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Obese Individuals Have Higher Preference And Sensitivity To Odour Of Chocolate

Lorenzo D. Stafford

Ashleigh Whittle

Department of Psychology, University of Portsmouth, U.K.

Correspondence to be sent to: Lorenzo D. Stafford, Department of Psychology, University of Portsmouth, King Henry Building, King Henry I Street, Portsmouth PO1 2DY.U.K. Email: lorenzo.Stafford@port.ac.uk. Tel: 02392 846322. Fax: 02392 846300

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Abstract

The worldwide epidemic of obesity has inspired a great deal of research into its causes and consequences. It is therefore surprising that so few studies have examined such a fundamental part of eating behaviour; our sense of smell. The aim of the present study was to examine the differences in olfaction in obese and non-obese individuals. Participants (n=40) categorised as obese (Body Mass Index, BMI ≥ 30) or non-obese (BMI<30) completed a standardised olfactory threshold test to an ecologically valid food related odour (chocolate), followed by a taste test.

We found that compared to those not obese, obese individuals rated the chocolate odour as more pleasant and were substantially more sensitive to the odour. There was also evidence that their sense of taste was more acute for sour and salty tastants. Correlational analyses further revealed that those measures of olfaction and taste were positively associated with BMI. These findings suggest that obese individuals show increased sensitivity and preference for an odour associated to energy dense foods. They also suggest that differences in our sense of smell offer a promising area for future research in obesity.

Keywords

Olfaction, Odour, Sensitivity, Obesity, BMI

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Introduction

Obesity is a worldwide problem that carries serious health risks including cardiovascular disease and diabetes (Malnick and Knobler 2006). It also places a significant burden on a nation's health care resources and in the UK alone in 2007, was estimated to cost the National Health Service £4.2 billion (Health 2014). The fact that these problems are now affecting developing countries (Popkin *et al.* 2012) highlights the truly global nature of this epidemic. This makes the examination of the factors involved in obesity a top priority for all countries around the world. Obesity is the product of energy consumption surpassing energy expenditure, but understanding why some individuals have a higher propensity toward obesity is necessarily complex, involving a number of factors including lifestyle, metabolism and genetics (Aronne *et al.* 2009). One aspect that has received relatively little attention is the role of our sense of smell in obesity. This is surprising, given that the sensory properties of food play a key role in food preference and our ability to detect those properties is generally down to our sense of smell more than our other senses (Murphy and Cain 1980; Murphy *et al.* 1977). Hence the vast majority of what we commonly refer to as the 'taste' of food is actually processed by the olfactory and not taste system (Rozin 1982; Wysocki and Pelchat 1993). In an era of unprecedented growth of highly processed foods that populate our supermarkets, food manufacturers must compete for our custom and one central factor is food flavour. One could therefore infer, that our ability to acquire a liking for these new flavours and foods is driven to a large extent by our olfactory system. Additionally in recent years, evidence has suggested an even greater role for our sense of smell in food intake. For instance, we have known for some time that critical drivers of hunger and satiety are controlled at the cellular level by peptides and hormones such as orexin and insulin; and that these systems are expressed in olfactory related parts of the brain. More recent

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work has shown these metabolic factors target the olfactory bulb and olfactory mucosa and hence are involved in the initial steps of processing odours, before being relayed to higher parts of the brain (Palouzier-Paulignan *et al.* 2012). These higher parts of the brain include the orbitofrontal cortex, a region believed to be key in associating the reward value of the sensory (including smell and taste) properties of food (Rolls 2005).

Given the role of our sense of smell in eating behaviour, a pertinent question is whether there is a difference in olfactory function between obese and non-obese individuals. In part answer to this, human FMRI work demonstrated that exposure to preferred food odours led to differences in brain activation; for obese individuals there was greater activity in the hippocampal and parahippocampal areas but in contrast, activity was higher in the posterior insula for lean individuals (Bragulat *et al.* 2010). This suggests that neural processing of hedonic olfactory information differs in obesity and given the key role of the hippocampus in memory, that such cognitive processes may also be implicated in compulsive overeating. From a different perspective, research (Trellakis *et al.* 2011) found that the generally disliked odour of black pepper oil was rated as significantly less pleasant in obese versus non-obese individuals. One possible explanation for this finding is that the association of an odour to bitter tasting foods of generally lower calorific value is more negative in obese versus non-obese individuals.

In terms of more functional aspects of olfactory function, there is a surprising shortage of research. One study found that the incidence of olfactory dysfunction was higher in morbidly obese (BMI > 45) compared to moderately (BMI <45) obese individuals (Richardson *et al.* 2004) suggesting a possible link between poorer sense of smell and overeating (see also related animal work, Thiebaud *et al.* 2014). In contrast, when a food odour was used in more recent work, it

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was found that those high in Body Mass Index (BMI) were better at detecting food odours (Stafford and Welbeck 2011). It could be therefore, that obese individuals are actually more sensitive to odours associated to food and that this interacts with food consumption. However, that study was based on a median split of BMI, which could be considered as rather arbitrary. An alternative method would be to recruit individuals above and below a certain BMI that corresponds to obesity status, e.g. BMI > 30 (Herbert *et al.* 2006). Additionally, that study (Stafford and Welbeck 2011) did not measure liking for the food odour, which given the subject area and previous findings would appear important. One of the main aims of the current study was therefore to rectify these two limitations to test odour hedonics and threshold (sensitivity) in obese and non-obese individuals.

Another aim of the present study was to examine differences in taste perception in these populations. It is important to note that humans have an innate preference for sweet tasting foods (Steiner 1979) that together with an aversion to bitter tastes is likely based on evolutionary adaptation, where sweet frequently signaled the presence of edible and energy-rich food such as ripe fruit, whereas bitter the opposite and possible poisons. In times of food scarcity, where energy expenditure to seek out food was high, these strategies of targeting foods high in sugar and fat were of clear advantage to humans. Evidently, these conditions are now reversed in many countries around the world, with plentiful supplies of such foods available with relatively little effort. From this background, it may appear obvious that obese individuals have simply failed to re-train themselves to the current food landscape and to an extent this is supported by data showing a preference for higher lipid and sucrose tasting foods in obese individuals (Drewnowski *et al.* 1985; Golay *et al.* 2005). Additionally, a positive relationship has been found between

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dietary fat intake and high BMI (Macdiarmid *et al.* 1998). Hence obese individuals have a preference for food types associated with increasing BMI, but what about actual differences in taste perception? One study found that obese individuals rated sweet tastes less intense than non-obese individuals, but reported that sweet tasting food were preferred more by obese subjects compared to leaner individuals (Bartoshuk *et al.* 2006). Such findings could suggest that an impaired sense of sweet taste in obese individuals results in greater food consumption, presumably to obtain the same levels of reward as their non-obese counterparts. Against that theory however, one study found that individuals with a higher body mass index (BMI) reported a lower preference for sweet tasting foods than leaner individuals (Felsted *et al.* 2007). Apart from sweet taste, it is also important to consider alterations in perception of savoury foods, especially when one considers the increase in the availability of processed foods and their high salt content (Rolls 2003). Interestingly here, there is evidence for *greater* sensitivity to salt in obese versus non obese groups (Pasquet *et al.* 2007).

In the present study, we therefore wanted to examine for the first time, how sensitive obese individuals were to an ecologically valid food odour (chocolate), associated to highly calorific foods. We also wished to investigate any differences in the perception of taste in four tastants (bitter, sweet, salty, sour). On the basis of previous research, we predict that sensitivity to the chocolate odour would be highest in the obese versus non-obese group and we tentatively expect taste perception would be more acute in the former.

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Method

Participants

Forty University students (25 females, 15 males) participated in the study and were aged between 18 and 24 years (M = 19.9 years, SD = 1.5 years). Participants were recruited using a variety of online systems (Sona participant booking system, social media) where the study was advertised as examining factors that influence our sense of smell & taste. All participants were non-smokers, reporting good health and not currently in any weight loss programs or taking appetite suppressants. Participants with problems with their sense of smell and taste were excluded as were underweight individuals (BMI <18.5). All participants gave written informed consent and the study protocol was given ethical approval from the department's ethics committee (British Psychology Society guidelines, consistent with the declaration of Helsinki).

Design

The study used a between-subjects design where according to participant's (Table 1) Body Mass Index (BMI), they were allocated to either the Non-obese (<30) or Obese (≥30) group. The main dependent variables were their olfactory threshold scores and taste acuity measures.

Materials

Olfactory Threshold Test

The odour used for the threshold test was a sweet smelling dark chocolate odourant (Code 0679, Anglo brands, UK) which was diluted in propylene glycol (Fisher Scientific, UK). The odourant was prepared using fifteen 250ml squeeze bottles, in 15 dilution steps, starting at 0.125% (Step 1) with each successive step diluted by a factor of two using serial dilution to the lowest (Step 15). In addition to the odour containing bottles, for each dilution step, two 'blank' squeeze bottles

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(containing dilutant only) were used in the threshold test. Testing commenced by asking participants to smell the bottle with the highest concentration to familiarise themselves with the target odour. They were then presented with the triplet containing the weakest concentration. Following presentation of the last bottle of the triplet (counterbalanced), participants were asked which bottle contained the odour (1, 2 or 3). If the participant answered correctly (and it was the lowest concentration), they were presented with the same triplet again (in a different order) and the task repeated until they made a mistake, which resulted in the triplet containing the next concentration step being presented. Using a single up-down staircase system (as used widely in olfactory research, e.g. (Hummel *et al.* 2007)), this was then repeated until there were seven 'turning points', with the mean of the last four points determining the threshold for the individual. Each bottle was held under the participant's nose (≈ 2cm) and gently waved between each nostril to ensure optimal inhalation. A blindfold was used by the participants to avoid odour identification. The experimenter wore cotton gloves (Boots, Portsmouth) to reduce any cross contamination of odours.

Gustatory Test

Suprathreshold taste was examined using a kit which is part of a larger test from the 'Sniffin sticks' battery (Burghart Instruments, West Germany) which has been used widely in research (Seo and Hummel 2009). In the test here, four bottles were used with spray attachments, each containing 10g distilled water plus the following: Sour (0.5g citric acid), Salty (0.75g NaCI), Bitter (0.005g quinine hydrochloride), Sweet (1g sucrose). Participants were presented with each tastant (counterbalanced order) which was sprayed directly onto the tongue by the experimenter. After each taste, they completed Visual Analogue Scale (VAS) ratings using 100mm unmarked line labelled "not at all" and "extremely" at either end, with the adjective "intensity";

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"pleasantness"; "bitter"; "sweet"; "salty"; "sour" centred above the line. Participants sipped some water before each taste.

Procedure

Participants were instructed to refrain from eating, smoking and chewing gum, within 2 hours of their testing session. The study took place between 0900 and 1300 at the University's Department of Psychology. The room used for the study was large and well ventilated to avoid other odours in the room affecting the results of the odour test. Participants completed an informed consent form followed by ratings of how hungry they felt using VAS. Next, they rated the intensity and pleasantness of the chocolate odour (strongest concentration) followed by the threshold test. They then completed the gustatory test for the 4 taste sprays. On completion of this test, participants were given a full debriefing and thanked for their time.

Data Analyses

For both olfactory and taste acuity tests, data were analysed using SPSS (version 22.0 for Windows, SPSS, Inc.). The threshold data were analysed using a Univariate ANOVA with Group (Non-obese/Obese) as the between-subjects factor. The same test was applied separately for the odour ratings (intensity, pleasantness). For the taste acuity tests, a multivariate analysis of variance (MANOVA) was used in order to explore each tastant's ratings for bitterness, sweetness, saltiness, sourness, pleasantness and intensity, using Group (Non-obese/Obese) as the between-subjects factor. Since previous research has shown evidence for the level of hunger (provided with/without lunch before testing, Stafford and Welbeck 2011)) to influence olfactory sensitivity, we completed the above analyses (including taste) with baseline hunger ratings as a covariate. This revealed no significant effect of hunger and for clarity we present the unadjusted

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means in the Results section.

Results

Odour Tests

For the threshold test, analyses revealed a significant effect of Group, $F(1, 38) = 32.24$, $p < .001$, $\eta^2 = 0.46$, where consistent with prediction, the Obese group were more sensitive to the chocolate odour (M = 14.13, SE = 0.38) than the Non-obese group (M = 10.24, SE = 0.57) (Figure 1). For the VAS ratings, we found an effect for odour pleasantness, $F(1, 38) = 7.21$, $p = .01$, $\eta^2 = 0.16$ where as expected, obese individuals rated the chocolate odour as more pleasant (M = 71.5, SE = 5.2) compared to the non-obese group (M = 53.9, SE = 4.0).

Taste Tests

Analyses of the taste VAS ratings revealed significant effects for Salty, $F(1, 38) = 5.39$, $p = .03$, $\eta^2 = 0.12$, with the obese group rating the tastant as more salty (M = 94.8 SE = 1.5) than the non-obese group (M = 89.0 SE = 2.0). Similarly, for the sour tastant, $F(1, 38) = 4.20$, $p < .05$, $\eta^2 = 0.10$, we found the obese group rated the tastant as higher in sourness (M = 91.2 SE = 2.2) than the non-obese group (M = 80.2 SE = 4.9). The effects for bitter and sweet tastants were not significant. These findings partially agree with the prediction of higher taste acuity in the obese versus non-obese group.

Correlations

To further explore the relationship between BMI, olfaction and taste, we completed correlations between BMI and the variables where we found clear differences in the above analyses: odour threshold, pleasantness, sour tastant(sour), salt tastant (salty). As can be seen in Table 2, the

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analyses demonstrated that all of these measures were positively associated with BMI, with stronger associations for the two olfactory measures. These findings suggest that increases in these dimensions of olfaction and gustation are associated with higher BMI.

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Discussion

The main findings of the study were that consistent with prediction, obese individuals (BMI≥30) were better at detecting the chocolate odour compared to the non-obese group. To our knowledge, this is the first study to specifically examine olfactory threshold to a food odour in obese versus non-obese adults. The direction of the finding is consistent with our previous study (exp 2) (Stafford and Welbeck 2011) where those high in BMI showed higher acuity to a food related (herbs) odour. Additionally, by recruiting participants with a widely used BMI threshold, we can be more confident that the effects relate to obesity, which also permits comparison to related research. Previous work in this area has found evidence for higher incidences of olfactory dysfunction in obese populations (Richardson *et al.* 2004), which might appear to contradict the current findings. However, unlike the present work, that study did not utilize an odour specifically related to food which may well account for the divergent findings. Indeed, in our previous study(exp 1) (Stafford and Welbeck 2011) olfactory sensitivity to a 'non-food' odour was also found to be poorer in those with higher BMIs, consonant with that earlier work. Collectively these findings suggest that obese groups are characterized by having a better sense of smell to food but not non-food odours. Another novel finding was that the pleasantness ratings for the chocolate odour were higher in the obese versus non-obese group. Interestingly, an earlier study reported no differences in odour pleasantness for benzaldehyde (bitter almonds) between healthy young obese and non-obese individuals (Thompson *et al.* 1977), whereas at the other end of the hedonic spectrum, work found that pleasantness for a black pepper oil was lower in obese compared to non-obese subjects (Trellakis *et al.* 2011). Taken together, it could be that differences in pleasantness between obese/non-obese groups materialize at the extreme ends of the spectrum. So, for odours such as chocolate that have a clear association to highly calorific

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foods, preference is clearly visible in obese individuals, whilst the reverse is true for odours such as black pepper oil, that have a much weaker association to energy dense foods. Given these sharp contrasts in both sensitivity and preference, it could be theorized that alterations in processing food odours in obese populations might actually facilitate excessive food intake. Relevant here, the orbitofrontal cortex is the centre for bringing together sensory inputs from smell and taste to produce overall perception of taste (Rolls 2005); the same area has also been shown to be activated during a reward/punishment task related to addictive behaviour such as gambling (Rolls and Grabenhorst 2008). If we also view Obesity as a form of addiction, as proposed elsewhere (Latner *et al.* 2014), it could be that odours related to highly rewarding foods act as 'kindling' to induce food craving, analogous to how drug cues invoke craving in drug addicts (Ballenger and Post 1978; Robinson and Berridge 1993). Furthermore, incentive sensitization theories of addiction propose that addicted individuals are overly sensitized to drug cues, suggesting that even short exposures to drug associated paraphernalia (e.g. packet of cigarettes) can induce craving and drug seeking (Robinson and Berridge 1993). In a similar way, obese individuals are more sensitive to food odours and presumably would work harder to secure the associated foods. In support of this, animal work has shown that obese mice were faster to detect food than non-obese mice (Getchell *et al.* 2006), suggesting a greater motivation to seek out food rewards.

The present study also found differences in taste perception in obese versus non-obese groups. The salty tastant was perceived as more salty in obese compared to non-obese individuals, which is in general agreement with previous threshold work where sensitivity was higher for salt in massively obese compared to non-obese adolescents (Pasquet *et al.* 2007). Better detection of

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salty foods might also be important in the finding that obese versus lean adults consumed a higher proportion of their dietary energy from salty foods (Cox *et al.* 1999). However, this would also seem to predict greater sensitivity to other savoury tastants such as umami (monosodium glutamate), which was in fact found to be poorer in obese versus normal weight females (Pepino *et al.* 2010), but paradoxically better in overweight compared to normal weight men (Donaldson *et al.* 2009). It therefore appears that at present, there is no clear relationship between sensitivity to savoury tastants and obesity. In terms of our finding that the sour tastant was perceived as more sour in the obese versus non-obese group, this may support the finding of increased neophobia (fussy eaters) in obese compared to non-obese children (Monneuse *et al.* 2008). Hence, one might theorise that if individuals are rating the sour tastant as higher in sourness, that this might be a factor in obese childrens' greater fussiness to foods that are generally more sour; which also tend to be foods lower in energy density.

The correlational analyses further revealed that increases in olfactory (sensitivity & pleasantness) and taste (salty/sour acuity) were associated with BMI. This could be interpreted as broader evidence for the influence of smell and taste in weight increases, but of course neither directionality or causality can be shown from these data alone; hence it could also be the case that such alterations in olfactory/gustatory function are a consequence of increased BMI. Interestingly, this latter explanation may be the more likely, since from a different perspective, the olfactory function of recovering anorexics began to improve as BMI increased (Aschenbrenner *et al.* 2008).

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The current study used a food odour high in ecological validity. Nevertheless future research is needed to understand how generalizable these findings are to other 'sweet' related odours but also to odours connected to savoury foods, e.g. pizza. It also needs to be recognised that the taste tests used in this study were looking at taste acuity/perception rather than taste threshold (sensitivity). We also recognize that since the taste tests were always completed after the olfactory tests, there is a possibility of an order effect; performance on taste tests affected by olfactory tests. The rationale for using a fixed test order, as with many other studies (Aschenbrenner *et al.* 2008; Seo and Hummel 2009; Stafford *et al.* 2013) is to avoid the larger problem of our sense of smell being affected by recent consumption. Nevertheless, to avoid this problem, future studies could possibly test participants on smell and taste at different sessions. In terms of the subjective (VAS) ratings participants made for the odour and tastants, it could be argued that a more precise measure would have been the General Labelled Magnitude Scale (gLMS, Bartoshuk *et al.* 2005)). The advantage of that scale is that it attempts to take account of differing perceptions of 'not at all' and 'extremely'. On a broader point, though we found differences in olfactory/gustatory processing between obese and non-obese individuals, these tests were completed independently, which is in contrast to the interactive way smell and taste operate during eating. Hence, further work is required to examine if such contrasts also appear in overall flavour perception, necessarily using retronasal rather than orthonasal olfactory designs. Such research should also investigate differences in the taste perception of dietary fat, especially as recent work has shown that dietary fat intake was associated with taste sensitivity (Tucker *et al.* 2014).

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In summary, we found that an odour strongly associated to sweet calorific foods was found to be more pleasant by obese individuals who were also better at detecting the odour compared to those not obese. Though differences in salty/sour taste perception were also found, it is theorized that alterations in olfactory function to food odours may well be a more fruitful area of research in understanding obesity.

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Table 1. Mean (SE) Participant Characteristics

	Non-obese	Obese
Age	19.4 (0.3)	20.4 (0.4)
Male/Female	5/15	11/9
BMI	20.3 (0.4)	31.3 (0.3)

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Table 2. Bivariate correlations Between BMI And Olfactory & Gustatory Measures (n=40)

	r	Significance
Olfactory Threshold	.66	P < .001
Olfactory Pleasantness	.42	P = .007
Salty Taste - Salty	.32	P = .047
Sour Taste - Sour	.37	P = .02

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Legends for figures:

Figure 1. Mean (±SE) Olfactory Threshold For Non-obese And Obese Groups

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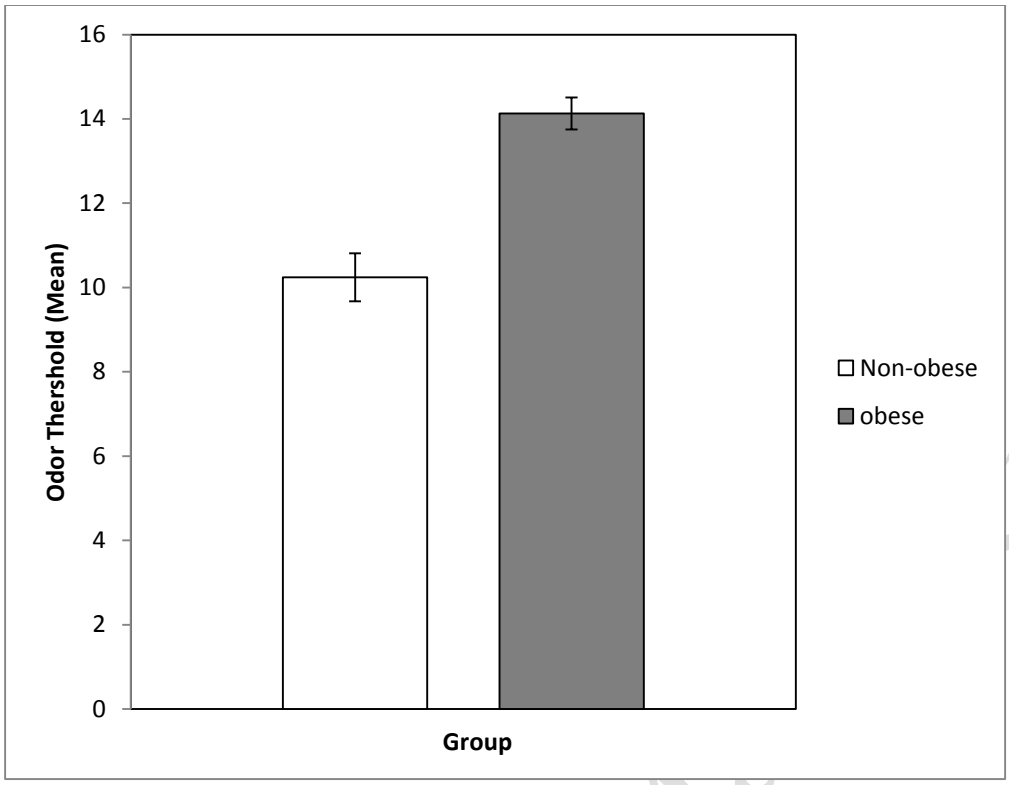

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